ASYMMETRICAL TASK LIGHTING
FOR
WORKSTATIONS WITH
VISUAL DISPLAYS UNITS

by

SANTHANAKRISHNAN N.

B.Tech (Mechanical), University of Kerala, India, 1986

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

College of Engineering

Department of Industrial Engineering

Kansas State University

Manhattan, Kansas

1988

Approved by:

Major Professor

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to express my thanks and gratitude to my major professor, Dr. Stephan A. Konz for his help, guidance and constant support. A special thanks is extended to my committee members, Dr. Louis E. Grosh and Dr. Eugene Russell.

I take this opportunity to thank the entire faculty and staff of the Industrial Engineering Department for their support and encouragement throughout my course of study at Kansas State University.

I am extremely greatful to my parents, whose support and encouragement are constant remainders to pursue excellence. It is to them that this work is dedicated.

1. LITERATURE REVIEW

1.1 INTRODUCTION:

Lighting has been, and continues to be, cited as one of the most critical elements of the comfortable, productive interior. Minimizing eye discomfort and the headaches and fatigue that are symptoms of eye discomfort (Dianof, Hap and Crane, 1981) must be of primary consideration.

Conventionally, lighting design and specification were considered only for "horizontal" tasks. The advent of the vertical Visual Display Unit (VDU) screen makes lighting design and specification more difficult. Now both horizontal (paper) and vertical (VDU) tasks must be considered. It is estimated that by the year 1990 there will be 40 million VDUs in use - one VDU for every three office workers (Smith, 1985). Redesigning the workplace to accomodate this equipment has prompted re-evaluation of task lighting requirements.

Instead of lighting designs for typically horizontal surfaces, the challenge is to eliminate glare on the vertical, highly reflective surface of the VDU screen. Without proper lighting design, visual discomfort by the VDU operators will increase.

1.2 ILLUMINATION FOR VDU OPERATORS

The source and intensity of light in the traditional paper handling office is detrimental to VDU use. Because VDUs generally present information with light characters on a dark background, less light is recommended for optimum VDU viewing (Springer, 1981). When ambient illumination is too high, contrast glare is produced. In other words, contrast between characters and screen background is reduced (Steward, 1980; Wooton, 1981). This results in reduction of character legibility. So low ambient illumination is widely used to reduce glare.

To reduce this glare, Osterberg (1976) recommended that offices with VDUs be illuminated between 300 to 350 lux, which he later reduced to 200 lux (Osterberg, 1979). Later Cakir, Hart and Steward (1979) recommended a range of 300 to 400 lux (after taking illumination for the task document into consideration). Bennett (1981) recommended ambient illumination between 250 to 500 lux for performing visual tasks of low contrast (word processing or data entry). Rowe (1982) suggested that the minimum illumination levels be lowered to 200 lux. Later Isensee and Bennett (1983) suggested that maintaining office area ambient illumination below 420 lux would reduce discomfort glare.

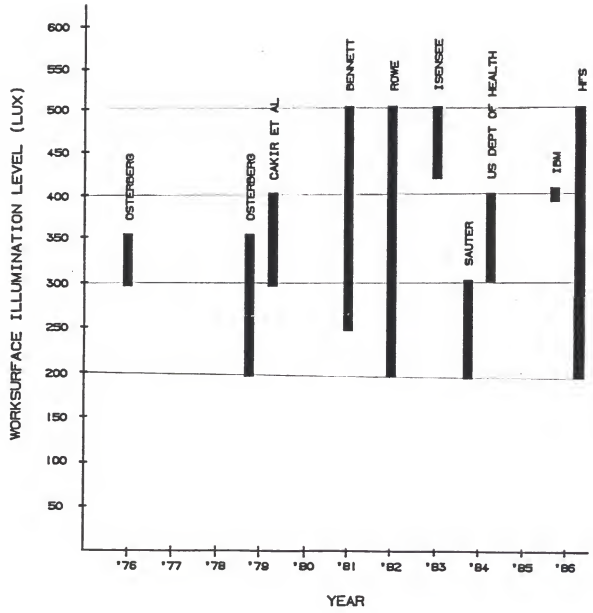


FIGURE 1.1 Summary of recommendations for worksurface illumination level in VDU workstations

The ideal illumination level for VDU viewing as recommended by the Illuminating Engineering Society of America (1981) is between 50 to 100 lux. The higher illumination level (values at the desk top) of 500 to 700 lux may result in 'operator experiencing visual discomfort. Sauter, Chapman and Knutson (1984) determined that satisfaction with lighting in paper work does not improve much at levels in excess of the 500 to 700 range. They also suggested that ambient illumination of 200 to 300 lux be supplemented with task document lighting. This allows the document to be illuminated within the 500 to 700 lux range.

For VDU operations, the US Department of Health and Human Services (1984) recommended a illumination range of 300 to 400 lux. The Human Factors Center of IBM (1984) suggested that 400 lux be set as a standard for VDU operations. The Human Factors Society (1986) suggested that an illuminance between 200 to 500 lux, measured on the work surface, is sufficient for workplaces with VDUs. The summary figure of the suggestions is shown in Figure 1.1.

Yearout and Konz (1987) investigated the optimum illumination levels for offices with VDUs. The illumination, provided by a mixture of direct and indirect lighting sources, was held at 350 lux at the workstation. They found that the operators preferred an intermediate

illumination level (800 lux) in the office space to their front. Operators also preferred increased brightness contrast on the wall. They concluded that design should consider not only the workstation but also the surrounding.

1.3 TASK LIGHTING

A typical task has different lighting requirements for the screen (fairly low ambient light with minimum glare), source documents and tasks when not using the VDU (fairly high ambient light), and the keyboard (medium lighting) (Figure 1.2). General lighting from the ceiling tends to light the entire work area evenly; this tends to be too much light and glare on the screen and too little for non-screen tasks. Task lighting seems to be a desirable alternative. In task lighting , the amount of light for the screen, non-screen tasks and keyboard are tailored for each of the three.

"Task" lighting refers to the localized lighting at the workstation to replace or supplement "ambient" lighting systems (usually overhead fixtures) used for more generalized lighting of the workplace. Task lighting is handy for lighting the source document whose visibility may suffer as ambient light is controlled to reduce direct glare and screen reflections. But, because task lamps are in close proximity to the source document (which is is close to

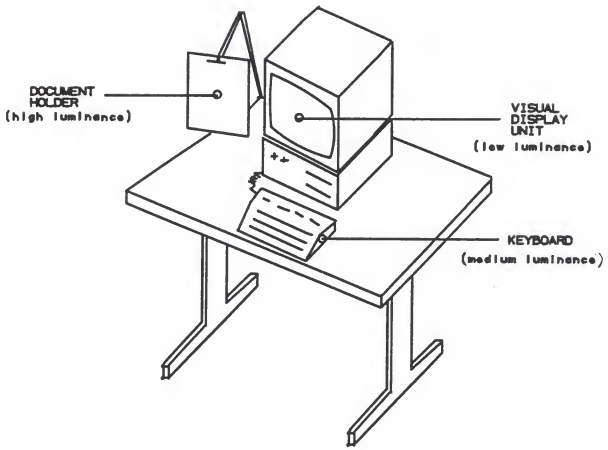


FIGURE 1.2 Lighting requirements for a VDU workstation

the line of sight in viewing the display), they represent a potential source of discomfort glare. And, if the task lamp (and thus the document) is very bright, display visibilty may be impaired momentarily as the operator looks from the document to the display (while the sensitivity of the visual system adjusts to the dimmer display). Another potential problem is that excessive light spread from the task lamp will contribute to diffuse reflections from the display. To prevent these problems, task lamps should be no more powerful than necessary, and be carefully shaded. The task lamps used for this experiment had 25 watt incandescent bulbs. Some task lamps are equipped with baffles or parabolic louveres to help control light spread.

Miller (1985) found that operators preferred to use a document task light. Bennett (1986) used three types of lighting: direct diffuse (650 lux), direct louvered (600 lux), and kiosk/task lighting (750 lux). The operators preferred the direct lighting conditions (without the task light) over the kiosk/task lighting. No preference between diffuse and louvered was reported. Operators stated that the kiosk/task lighting was too bright.

AT&T's Communication headquarters in Pittsburgh, PA, experienced VDU surface glare on a large scale at long-line computer terminal areas on three of the building's floors. To reduce the worksurface glare problem, AT&T retrofitted

its task light flouroscent fixture with a manually adjustable light regulating system. The system uses an optical sensor to relay the illumination level information to the solid state unit, which automatically adjusts the light to maintain a constant pre-set level as desired by each individual (Lighting Design + Application, 1986).

According to the Dutch Interior Lighting Recommendations (1981), almost all luminaires appeared to have too low and non-uniform illuminance at the working plane. Leebeek and Ellens (1983) investigated a sample of 30 table luminaires. They found that the luminances in the direction of the eye of many luminaires are so high that glare will be unavoidable. When VDUs were used in combination with most luminaires, very annoying specular reflections were visible in the screens.

1.4 DIRECT VERSUS INDIRECT LIGHTING

A major concern in the VDU workplace lighting is the horizontal dispersion of light. Because the gaze of the VDU operator is directed toward a relatively dim display at a near horizontal angle, lighting fixtures which disperse light horizontally create the opportunity for discomfort glare. Controlling horizontal dispersion of light also is important for preventing screen reflections.

The use of unshielded overhead lamps is never a good idea in

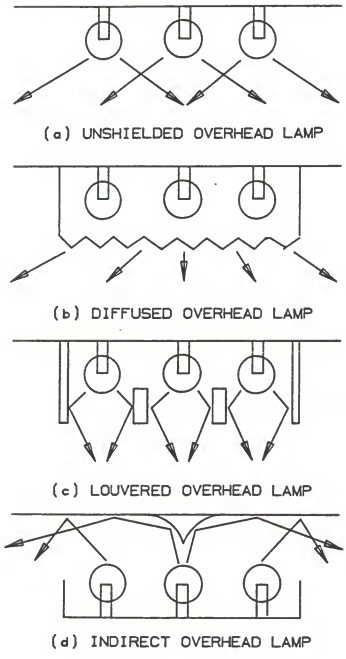


FIGURE 1.3 Different types of lighting fixtures

a VDU workplace since light is dispersed at wide angles (Figure 1.3a). Similarly, light fixtures enclosed with a refractor-type lens - for example, the roughened plastic panel commonly used with a flouroscent tube fixture (diffused light) - also creates a broad spread of light (Figure 1.3b). The advantages of diffused lighting (1.3c and 1.3d) are fewer glare surfaces (hot spots) in the visual field and a more uniform spread of light (IBM Human Factors Center, 1984).

Another solution to the control of horizontal dispersion of light from fixtures is the use of traditional louvers or baffles (Figure 1.3c). Light at wide angles is blocked. Finally, indirect lighting is sometimes recommended for VDU facilities. With indirect lighting, light from the fixture is reflected and diffused from the ceiling (Figure 1.3d). This effectively removes light fixtures as a source of direct glare or sharp reflections to operators, but the broad spread of light from the illuminated ceiling can contribute to diffuse reflections from the VDU (Sauter, Chapman and Knutson, 1984).

Harvey, Mistrick, DiLaura, and Nagi (1984) found a preference for indirect lighting. Their study did not find a statistically significant difference in the productivity of the tasks. They used 3 lighting conditions: direct (415 lux), indirect with a single lamp (415 lux) and indirect

contribute to diffuse reflections from the VDU (Sauter, Chapman and Knutson, 1984).

Harvey, Mistrick, DiLaura, and Nagi (1984) found a preference for indirect lighting. Their study did not find a statistically significant difference in the productivity of the tasks. They used 3 lighting conditions: direct (415 lux), indirect with a single lamp (415 lux) and indirect with a double lamp (520 lux). Task document lights were not used. The order of the operator preference was the indirect with a double lamp, indirect with a single lamp, and direct.

Miller (1985) and Kendrick and Harris (1985) found a preference for indirect lighting combined with task lighting, but found no significant differences in the results between it and direct lighting. Kendrick and Harris (1985) examined mean illumination at the task document for three conditions: direct (510 lux), indirect (120 lux) and indirect with task document lighting (1030 lux). The subjects preferred the indirect with task document lighting most, followed by direct light source and indirect source.

Bennett (1986) studied the lighting effects on worker performance and the worker's comfort concerning the lighting and the glare produced by the lighting conditions. The independent variable was lighting. The types of lighting were: (1) Indirect plus direct illumination (340 lux) was

provided by kiosks and a task document light, (2) direct illumination using diffused light (1300 lux) and (3) louvered ceiling (1200 lux) fixtures. The subjects preferred direct (louvered direct then diffused direct lighting) to the indirect plus direct source.

Yearout and Konz (1987) found that when general illumination at the workstation was held at 350 lux, VDU operators preferred indirect plus direct over direct only illumination.

An asymmetrically designed lamp is now available, with which light can be distributed at an oblique angle to eliminate glare and shadows. The shade may be rotated 360 degrees in a horizontal plane so that light may be directed where required.

2. EXPERIMENTAL SETUP

2.1 Introduction

This experiment was done to test the performance differences of subjects under six lighting conditions. Two task lights were used (the asymetrical in four different positions, the symmetrical and one condition without a task lamp) at a constant room ceiling lighting condition.

Prior to their arrival at the lighting laboratory, subjects wearing contact lenses were informed to wear their glasses for the experiment. Subjects were draped in a black bib to minimize glare problems resulting from the lighting conditions. Each subject was allowed a practice trial, prior to collecting data. This familiarized the subject with the experimental procedures and the lighting environment ballot (Appendix C).

Prior to each experiment, subjects were assigned a number for coding their data. This was to maintain subject anonymity. Subjects then read the subject orientation (Appendix A) and signed an informed consent statement (Appendix B).

2.2 Lighting Laboratory Description

The lighting laboratory is located in room 134 of Durland Hall, Kansas State University. This 31 x 12 x 8 foot room has been designed to test different types of lighting preferences in a simulated office environment. The laboratory layout is shown in Figure 2.1.

It is furnished with a soft beige carpet as suggested by Christensen (1981). The walls and the cubicle dividers are of a light cream color. The ceiling is covered with a white non-reflective soundproof fiberboard.

The fixed direct illumination sources are fourteen 2 x 4 and two 2 x 2 foot overhead flourescent lights (Fig. 2.2). Lighting fixtures are either louvered (4 inch) or diffused. Each fixture contains two F40WW warm white lamps. The louvered direct illumination sources were used for this experiment.

The laboratory also is equipped with three 16 x 16 kiosk fixtures that reflect light off the laboratory ceiling (indirect illumination). Each fixture contains one 175 watt metal halide lamp. The fixtures can be easily moved about. A kiosk was used to prevent glare on the screen caused by the direct louvered source at the back of the workstation. This fixture was placed in between the workstation and the

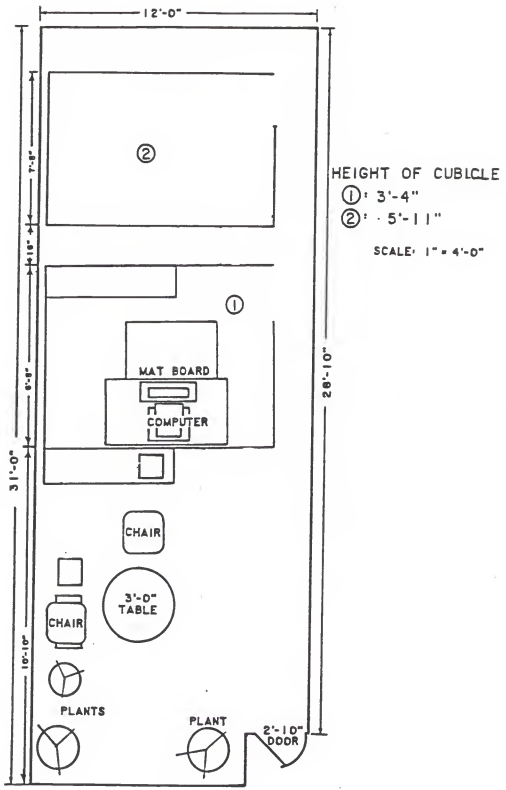


FIGURE 2.1 Illumination laboratory floor plan

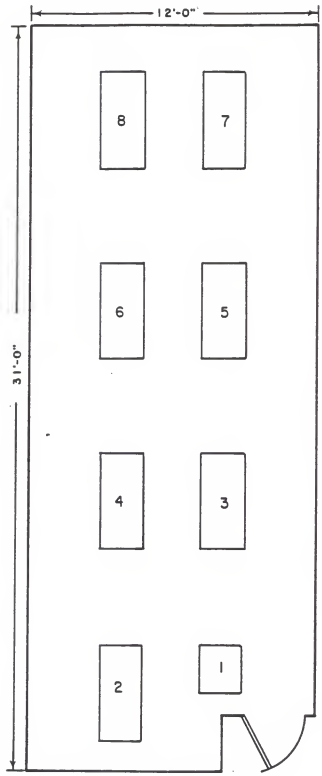


FIGURE 2.2 Lighting laboratory louvered ceiling fixtures

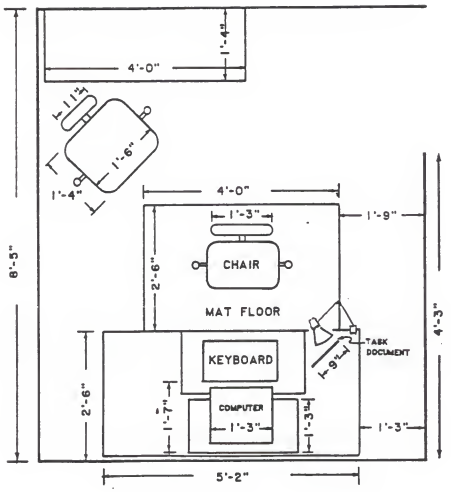
illumination source (Figure 2.2).

2.3 Workstation

The workplace consisted of an adjustable work table, an adjustable chair, and partitions to set it apart from the other areas of the room as in an office. The cubicle dividers were 42 inches tall and defined a work area of 7 x 8 ft. Figure 2.3 is a scale drawing of the workstation cubicle. Prior to beginning the experiment, the subject was allowed to adjust chair. The keyboard height was kept constant at 26" for all conditions.

The computer used was an IBM PC (Model 5153) and the monitor was an IBM PC color display (Model 5150). A glare shield was used for all conditions. It fits over the terminal top and effectively blocks light reflection and reduces glare. Two different kinds of task lamps were used for this experiment. They were a asymmetric lamp and a symmetric lamp. The same 25 W incandescent bulb was used for both the task luminaires. Appendix D is a photograph of the two task luminaires.

An asymmetrically designed lamp distributes light at an oblique angle to eliminate glare and shadows. The shade may be rotated 360 degrees in a horizontal plane so that light may directed where required.



SCALE: 1" = 2'-0"

FIGURE 2.3 VDU workstation diagram

3. EXPERIMENT DESIGN

3.1 Introduction

Subjects were tested at a VDU workstation to analyze their preference of the six different conditions; see Appendix I.

3.2 Task

The subjects keyed the text for 6 minutes. The text were six photocopied pages from David Rick's book "International Business Blunders" (Appendix E). The text was placed on a document holder on the table. After keying for 6 minutes, there was 4 minutes to fill in the lighting environment ballot (Appendix C) and change to the next lighting condition. The subject was required to walk over to the laboratory door and return to the workstation after completing the ballot. After evaluation was complete, a new condition was tested.

3.3 Subjects

The subjects (9 males and 6 females), who were students of IE 554 and IE 625, took part in the experiment. The 15 subjects were given extra credit in their respective courses. The ages of the subjects were between 20 and 27 years.

3.4 Design

The general workstation illumination was held at 350 lux for all the six lighting conditions. The direct louvered ceiling fixtures were used to illuminate the room. Cool white overhead flouroscent lights with 4 inch louvered fixtures were the source of the direct lighting. Fixtures 2, 4 and 8 were on to attain the above illumination level at the workstation. The distribution of illumination that resulted from this combination is shown in a contour diagram figure (Appendix F). This 350 lux is within the IES recommended 300 to 500 lux for VDU word processing type tasks (Konz, 1983) and is at the mid-range point of the 200 to 500 lux recommended by Human Factors Society (1986).

Task lighting was provided by two different task lamps. They were a asymmetric lamp and a symmetrical lamp. The asymmetrical lamp was used in 4 different positions. One of the conditions was without a lamp. The six different conditions are shown in Appendix I. The illumination distribution contour diagrams for the lamps are shown in Appendix G.

Table 3.1 Factor Combinations

FACTOR	LEVEL	CODE
task lighting	6	asymmetrical (4 positions), symmetrical and without lamp

The subjects reported on their respective test dates. Upon arrival they were briefed on the experiment, had their eyes tested, conducted a trial run and were treated with the 6 experiment conditions. A random number generator function of a calculator was used to select the prescribed random sequence of these treatments (Appendix H). Each condition began with a new task document page.

3.5 Procedure

There were 6 experimental conditions (Appendix I). Each trial took 10 minutes (6 minutes to key and 4 minutes to evaluate, change the lighting conditions). The time required for one subject to be briefed on the experiment and conduct 6 trials plus a practice trial was 1.5 hours.

3.6 Criteria

Three criteria were used:

(1) Operator preference.

(2) Number of words typed per minute during the 6 minutes keying period.

(3) Error rate (percent of misspelled words).

The single adjective scale recommended by Konz, Bennett and Miller (1986) was used, due to its increased sensitivity

over the typical paired semantic-differential scale. Adjectives were selected to determine comfort, pleasantness and esthetics of the ambient lighting conditions. The scale used was identical to the one used by Yearout and Konz (1987) in their experiment. This scale is shown in Appendix C. The scale was later converted from votes 1 to 7 to a score in percent by using the formula shown below:

Score (in percent) = ((vote - 1) / 6) * (100)

4. RESULTS

4.1 Introduction

The data was analyzed for possible data entry errors and outliers, then several statistics tests were run. These were Factor Analysis, Analysis of Variance and Multiple Comparisons (Appendix J). LSD and Paired Comparison T Test were used. This section will address each criterion and the tests performed. The significance level used for all tests of differences was 0.05. For more details, see Appendix J.

4.2 Factor Analysis

A factor analysis was made on the votes from the 12 adjectives (Appendix C) that describe the preference criteria. This analysis determined that the 6 adjectives which were designed to test workstation preference could be collected into a single variable "workstation" and the other 6 that tested the general room illumination could be collected into another variable "room illumination". The squared multiple correlation with each factor for workstation was 0.9721 and for room illumination 0.9245.

4.3 Workstation

An analysis of variance procedure was carried out on the

model using the criterion "workstation". Multiple comparisons were made using the Least Significant Difference test. The results determined that there was significant difference between the condition 4 (Appendix I) and the rest of the conditions. Table 4.1 illustrates this result.

Table 4.1: Task light for criterion "workstation"

Least Significant Difference is 15.7

LSD	T-Test	Mean	Condition No.
A	A	74.2	5
A	A	71.7	3
A	A	68.1	6
A B	A B	66.0	1
A B	A B	61.1	2
B	B	51.7	4

Means with the same letter are not significantly different.

4.4 Room Illumination

The criterion used to test the differences between preferences in the general lighting condition was "room illumination". This analysis determined that the subjects preferred the room illumination for condition 5 (Appendix I). Table 4.2 illustrates this result.

Table 4.2: General lighting for criterion "room illumination"

Least Significant Difference is 9.5

LSD	T Test	Mean	Condition No.
A	A	77.1	5
A B	A B	71.0	6
A B	A B	68.6	3
A B	B	68.3	1
B	B	64.5	4
B	B	64.4	2

Means with the same letter are not significantly different.

4.5 Performance

The criteria percent typing errors (Number of errors / Number of words typed) and number of words were examined to determine if the different conditions had any effect on the performance. An analysis of variance procedure was used and the least significant difference tests were conducted.

4.5.a **Percent Error**: There was significant difference between condition 6 (Appendix I) and the other conditions. Table 4.3 illustrates this difference. Mean percent error was 3.75.

Table 4.3: Task light for the criterion Percent Error

Least Significant Difference is 1.5%

LSD		T Test	Mean	Condition No.
A		A	2.6	6
A	B	A	3.6	5
A	B	A	3.7	4
A	B	A	3.8	2
	B	A	4.3	3
	B	A	4.4	1

Means with the same letter are not significantly different.

4.5.b Words per minute: The mean words typed per minute was 22.8. The least significant difference test shows that there were three different groupings. There were differences between [condition 6, condition 5], [condition 2, condition 3] and [condition 1, condition 4] (Appendix I). Table 4.4 illustrates this result.

A paired comparison test (Wilcoxon Test) was conducted to verify the above groupings and the results were found to be the same.

Table 4.4: Task light for criterion "words per minute"

Least Significant Difference is 1.1

LSD	T Test	Mean	Condition No.
A	A	24.4	6
A	A	24.2	5
B	B	22.9	2
B	B	22.9	3
C	C	21.6	1
C	C	20.8	4

Means with the same letters are not significantly different.

4.6 Test of Individual Adjectives

An analysis of variance procedure was carried out on the model for each of the 12 adjectives used in the lighting environmental ballot (Appendix C). Multiple comparisons were made using the Least Significant Difference test. Table 4.5 to Table 4.16 illustrates the results.

Table 4.5: LSD for adjective "agreeable"

Least Significant Difference is 1.0

Groupings	Mean	Condition No.
A	5.4	5
A B	5.1	1
A B	5.1	3
B	5.1	6
C B	4.3	2
C	4.1	4

Means with the same letters are not significantly different.

Table 4.6: LSD for adjective "desirable"

Least Significant Difference is 1.0

Groupings	Mean	Condition No.
A	5.0	5
A B	4.8	3
A B	4.7	6
A B	4.5	1
A B	4.4	2
B	3.8	4

Means with the same letters are not significantly different.

Table 4.7: LSD for adjective "good"

Least Significant Difference is 1.0

Groupings	Mean	Condition No.
A	5.1	5
A B	4.9	3
A B	4.9	6
A B	4.3	1
A B	4.3	2
B	4.0	4

Means with the same letters are not significantly different.

Table 4.8: LSD for adjective "satisfied with"

Least Significant Difference is 0.9

Groupings	Mean	Condition No.
A	5.3	5
A	5.2	3
A	5.0	6
A	4.9	1
A B	4.5	2
B	3.9	4

Means with the same letters are not significantly different.

Table 4.9: LSD for adjective "acceptable"

Least Significant Difference is 0.9

Groupings		Mean	Condition No.
A		5.4	3
A		5.3	5
A		5.1	1
A	B	4.9	6
A	B	4.8	2
	B	4.1	4

Means with the same letters are not significantly different.

Table 4.10: LSD for adjective "content with"

Least Significant Difference is 0.9

Groupings		Mean	Condition No.
A		5.2	5
A		5.1	3
A		4.9	1
A		4.8	6
A	B	4.5	2
	B	3.9	4

Means with the same letters are not significantly different.

Table 4.11: LSD for adjective "pleasant"

Least Significant Difference is 0.7

Groupings		Mean	Condition No.
A		5.4	5
A	B	5.0	1
A	B	5.0	6
A	B	4.9	3
	B	4.6	4
	B	4.5	2

Means with the same letters are not significantly different.

Table 4.12: LSD for adjective "harmony"

Least Significant Difference is 0.6

Groupings		Mean	Condition No.
A		5.3	5
A	B	4.7	1
A	B	4.7	6
	B	4.4	3
	B	4.3	4
	B	4.3	2

Means with the same letters are not significantly different.

Table 4.13: LSD for adjective "relaxed"

Least Significant Difference is 0.7

Groupings	Mean	Condition No.
A	5.3	5
A	5.3	1
A	5.1	6
A	5.0	4
A	4.9	3
A	4.9	2

Means with the same letters are not significantly different.

Table 4.14: LSD for adjective "interesting"

Least Significant Difference is 0.6

Groupings	Mean	Condition No.
A	4.5	5
A	4.5	3
A B	4.3	2
A B	4.2	4
A B	4.1	6
B	3.8	1

Means with the same letters are not significantly different.

Table 4.15: LSD for adjective "like"

Least Significant Difference is 0.7

Groupings	Mean	Condition No.
A	4.9	5
A B	4.8	3
A B	4.7	6
A B	4.4	2
A B	4.3	4
B	4.2	1

Means with the same letters are not significantly different.

Table 4.16: LSD for adjective "sociable"

Least Significant Difference is 0.7

Groupings	Mean	Condition No.
A	4.8	6
A	4.7	5
A	4.6	3
A	4.5	1
A	4.5	2
A	4.4	4

Means with the same letters are not significantly different.

5. CONCLUSIONS

5.1 Introduction

The purpose of this section is to summarize the findings of the experiment and then draw conclusions and design implications.

5.2 Task Lighting

VDU operators preferred conditions 1, 2, 3, 5 & 6 over condition 4 (-90 degrees from the screen) using the criterion "workstation" (see table 4.1). Position 5 (-150 degrees from the screen) was the best. The task document illumination was between 380 to 890 lux for condition 4 (Appendix I.b) and between 190 to 670 lux for the other conditions. To have a task document illuminated within this range when the workstation illumination is within the recommended 200 to 500 lux, a task light is required. The task document illumination for the condition with no table luminaire was between 190 to 210 lux. Since individual preferences vary, it is preferrable to have task lights with adjustable brightness controls at the workstation.

5.3 Performance

The error percentage was minimum for condition 6 (-250 degrees from the screen) and was significantly different from the other conditions 1 and 3 (Table 3.4). The task document illumination was between 290 to 410 lux, the illumination at the screen was between 45 to 70 lux and at the keyboard it was between 360 to 470 lux (Appendix I.c). The error percentage was 2.6. The highest error percentage of 4.4% was for the condition with no table luminaire (condition 1). The VDU operators made less errors with less light towards the screen. In other words they did better with the asymmetrical table luminaire to be positioned in such a way that light be directed away from the screen.

The words per minute was the maximum (24.4 wpm) for condition 6 (-250 degrees from the screen). For the condition with no table luminaire, words typed per minute was 20.8. Table 3.5 illustrates that wpm was maximum for conditions 5 & 6.. There was no significant difference among the different conditions. The asymmetrical lamp was positioned in such a way that light was directed away from the screen for both these conditions (Appendix I).

5.4 General Lighting

The general room illumination was the same for all the conditions. However, VDU operators preferred the room illumination with the 150 degrees orientation of asymmetrical lamp (condition 5) to the condition with the symmetrical lamp (condition 2) (Table 3.3).

5.5 Design Implications

A task light is required to maintain the task document illumination preferred by the VDU operator. The VDU operators should position the task light so as to minimize light towards the screen (conditions 5 and 6, i.e. -150 and -250 degrees from the screen). An asymmetrical table luminaire is recommended over the symmetrical table luminaire. The asymmetrical table luminaire can be positioned in way that there is less light on the screen and more for the task document, while a symmetrical luminaire distributes light in all directions equally (Appendix G).

REFERENCES

Lighting Design + Design, "Task Lighting System does the Job at AT&T", LD+A, February 1986.

Bennett, C., "Chapter 6:11, Lighting", Handbook of Industrial Engineering, Salvendy, G. (editor), John Wiley & Sons, New York, NY, 1981.

Bennett, C., "Lighting, Comfort and Performance in the Workplace", Lighting Design & Applications, Vol 16, No 8, 40-44, Aug 1986.

Cakir, A., Hart, D. and Steward, T., The VDT Manual, Darmstadt, West Germany: Ince-Fiej Research Association, 1979.

Christensen, M., "Lighting Prescription for Areas Containing Cathode Ray Tube (CRT) Displays, Lighting Design & Application, 23-25, May 1981.

Dainoff, M.J., Happ, A., and Crane, P., "Visual Fatigue and Occupational Stress in VDT operators", Human Factors, Vol 23, No 4, 421-438, 1981.

Harvey, L., Mistick, R. and Laura, D., "Quantifying Reactions of the Visual Display Operator to Indirect Lighting", IES Annual Conference, 515-546, 1984.

Human Factors Center, Human Factors of Workstations with Visual Displays, IBM Corporation, San Jose, CA, 1984.

Human Factors Society, "American National Standard for Human Factor Engineering of Visual Display Terminal Workstations, Revised Review Draft", Human Factors Society, Inc., Santa Monica, CA, 1986.

IES Lighting Handbook, Applications Volume, Kaufman, J. (editor), Illuminating Engineering Society of North America, New York, NY, 1981.

Isensee, S. and Bennett, C., "The Perception of Flicker and Glare on Computer CRT Displays", Human Factors, Vol 25, No 2, 177-184, Apr 1983.

Kendrick, D., and Harris C., "KSU VDT/Lighting Laboratory", Engineering Experiment Station, Kansas State University Report 168, Manhattan, KS, Jan 1985.

Konz, S., Work Design: Industrial Ergonomics, 2nd Edition, Grid Publishing, Inc., Columbus, Ohio, 1983.

Konz, S., Bennett, C. and Miller, B., "Task Lighting at a VDT Workstation", Proceedings of the Human Factors Society, 192-196, 1986.

Leebeeek, H. J. and Ellens, E., "Local Lighting with Table Luminaires", Proceedings 20th Session - Commission Internationale de l'Eclairage, E25, 1983.

Miller, B., "Task Lighting in a Video Terminal Workstation", Engineering Experiment Station, Kansas State University Report 170, Manhattan, KS, Mar 1985.

Osterberg, O., "Review of Visual Strain , with Special Reference to Microimage Reading", Proceedings of the International Micrographics Congress, Stockholm, Sep 1976.

Osterberg, O., "Visual Displays in the Offices", Environmental Design Newsletter of the Human Factors Society, Vol 10, No 1, 1979.

Sauter, S., Chapman, L. and Knutson, S., Improving VDT Work: Causes and Control of Health Concerns in VDT Work, Department of Administration, State of Wisconsin, Madison, Wisconsin, 1984.

Smith, M., "VDT Strain: Psychological Strain or Physical Basis", Proceedings of the Human Factors Society, 689-693, 1985.

Springer, T.J., "Visual Display Units in Office Environment", Proceedings of Symposium, Tufts University, May 1980.

Steward, T., "Problems Caused by the Continous Use of Visual Display Units", Lighting Research and Technology, Vol 22, No 1, 26-36, 1980.

Wooton, E., "Lighting for VDT Operation", HFA Communique, Vol 13, No 5, 1-3, Oct 1981.

Yearout, R., and Konz, S., "Task Lighting for Visual Display Unit Workstations", Proceedings of IX International Production Engineering Conference, Cincinatti, Ohio, 1862-66, 1987.

Yearout, R., and Konz, S., "Illumination levels in Offices with Visual Display Units", Proceedings of the Human Factors Society, 1113-1115, 1987.

Appendix A

SUBJECT ORIENTATION

Task Lighting for Workstations with Visual Displays

The purpose of this experiment is to evaluate operator performance and visual comfort while keying in a manuscript. You will be using an IBM Personal Computer and will be keying from a task document. This simulates typical word processing or data entry tasks. You will be exposed to 6 different lighting conditions.

After completion of this orientation, adjust the chair, keyboard, etc. to your preference. The experimenter then will open a document file. You then will begin to key into the computer from the task document. At the end of 6 minutes you will be told to stop keying. He will "save" your file.

While the experimenter is setting the new lighting condition, fill out a preference questionnaire. A sample questionnaire is attached to this orientation sheet. Write the number that best describes how you would rate the lighting environment. Upon completing this form, you will get up and walk over to the laboratory door and return to the workstation. Then you may rest until the experimenter

tells you to begin a new condition.

The experimenter then will open a new document file. On his instructions, begin keying in text from a new document. You will be exposed to 6 lighting conditions similar to the one described above. The total time to complete this experiment will be approximately 1.5 hours.

Your data will be coded with a number and your name will not be associated with the test results. These results will be held in strict confidence.

Since visual fatigue has no lasting effects, your participation in this experiment poses no danger to your health. You are to report at the time and place specified on the experimental subject sign up sheet available at the Industrial Engineering Office.

By your participation in this experiment you will be providing data on visual display units workstation preferences. This data will assist engineers in developing better workstations.

Appendix B

INFORMED CONSENT STATEMENT

TASK LIGHTING FOR VISUAL DISPLAY UNIT WORKSTATIONS

1. I, _____ volunteer to participate in a project in connection with research studies to be conducted by Kansas State University.

2. I fully understand the purpose of the study as outlined on the orientation statement, attached to this sheet.

3. I also understand that my performance as an individual will be treated as research data and will in no way be associated with me for other than identification purposes, thereby assuring ananymity of my performance and responses.

4. I understand that I am a volunteer for this research and that I may decline to participate with no penalty or loss of benefits to which I am otherwise entitled. I further understand that I will be permitted to leave the test at any time and I may discontinue participation without penalty or loss of benefits to which I am otherwise entitled.

5. I understand that I will recieve no monetary compensation for my participation.

6. There is no compensation by Kansas State University for injured research subjects.

7. I hereby agree not to give information regarding the studies to any public news media nor to publicize any articles or accounts thereof without prior written approval of Kansas State University.

8. If I have any questions concerning my rights as a test subject, injuries or emergencies resulting from my participation or any questions concerning the study, I understand that I can contact Santhanakrishnan N. at 776-2172.

I have read the Subject Orientation Statement and signed the herein Informed Consent Statement, this ____ day of _____, 1988.

_____
Signature

Appendix C

LIGHTING ENVIRONMENT BALLOT

Subject	: _____		
TITMUS	: _____	Age	: _____
Condition	: _____	No. words	: _____
Document Page	: _____	No. error	: _____

Instructions: Below is a list of words that can be used to describe the lighting environment. This list is divide into two parts. Part I, workstation environment, describes lighting around your work station. Part II, general lighting environment, describes the overall lighting for the room. Rate how accurately the words describe the workstation lighting environment and general lighting environment. Use the following 1-7 scale for your answer for each word.

1 = very inaccurate
2 = inaccurate
3 = slightly inaccurate
4 = NEUTRAL, neither accurate nor inaccurate
5 = slightly neutral
6 = accurate
7 = very accurate

WORKSTATION LIGHTING ENVIRONMENT

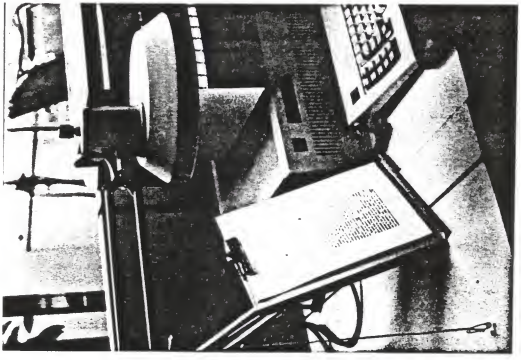
1.	agreeable ____	4.	satisfied with ____
2.	desirable ____	5.	acceptable ____
3.	good ____	6.	content with ____

GENERAL LIGHTING ENVIRONMENT

7.	pleasant ____	10.	interesting ____
8.	harmony ____	11.	like ____
9.	relaxed ____	12.	sociable ____

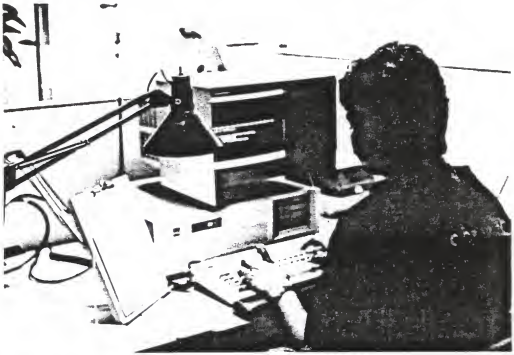
APPENDIX D

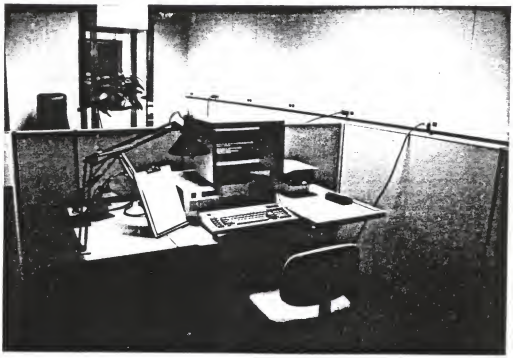
PHOTOGRAPHS OF ASYMMETRICAL LAMP ARRANGEMENT



APPENDIX D

PHOTOGRAPHS OF 'SYMMETRICAL LAMP ARRANGEMENT





Another soup story involves the French, who traditionally serve soup as the first course. In the more plush and class-conscious societal groups, "potage" is the preferred term for the soup appetizer. Ignorant of this tradition, a certain American food company tried to sell its "soup" at some eighty cents a can. Few French housewives were willing to spend eighty cents for a can of plain "soup"![24]

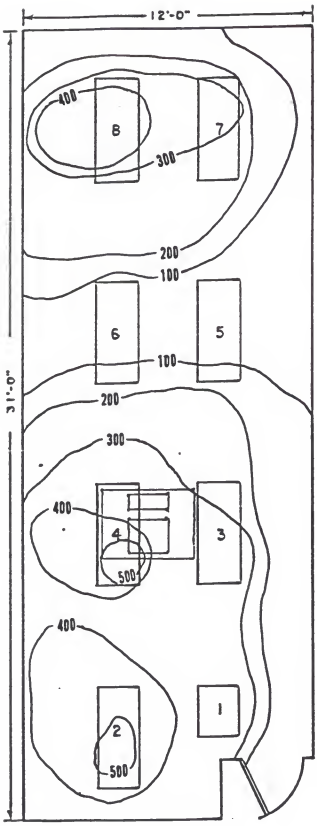
But soup is not the only product with which firms have had adaptation problems. Although "there's always room for Jell-O" in America, General Foods found that no one in England seemed to have shelf space for its famous dessert. Concerned about this strange lack of acceptance in a market where jello is an established item, General Foods investigated the situation. It turned out that English housewives traditionally have used gelatin formed in solid wafers or cakes and that Jell-O's powdered package was unfamiliar to them to the point of being unacceptable. After substantial losses and futile efforts at promotion, Jell-O finally gave up on the British.[25]

The importance of adaptation for product success, particulary for foods and consumer goods, to local tastes cannot be overemphasized. General Foods learned the lesson, and now adapts its coffee varieties to each foreign market. It has one blend for the British who like to take coffee heavily diluted with milk; one for the French who com-

proud of its own paper manufacturing facilities, despite the lack of standardization and quality control in production output. Unfortunately, the duplicating machines were highly standardized and could not easily accommodate the varying sizes of local paper. To the government, which was so proud of its paper manufacturing facilities, importing paper to suit the machines was unthinkable. As a consequence, the units already sold stayed idle and the market was quickly closed to the American firm. Had the firm considered local supply characteristics, it would not have needed to invest in making adjustments in the power specifications for a market that could not use the equipment or it could have better adapted the machine so that it could have been used.[28]

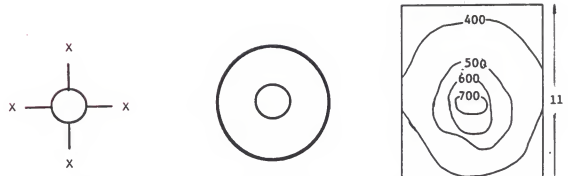
Tastes are different across the Atlantic, but even just across the U.S. border, consumer preferences have stayed the multinational giants, as Philip Morris, Inc. knows. It tried to convert the Canadian smokers to one of its very popular U.S. cigarette brands, but, despite a substantial advertising and promotional campaign, the Canadians preferred to fight rather than switch. Traditionally, Canadians have favored the so-called "Virginia-type" tobacco blends, and they held onto that preference. Lack of adequate market testing prior to entry was a major error on Philip Morris' part. Such staunch pedilection would have become obvious from any reasonable market test.[29]

Sample page from David Rick's book "International Business Blunders"

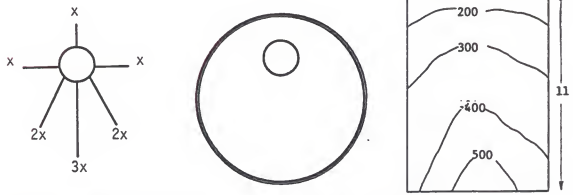


SCALE: 1" = 4'-0"

ILLUMINATION DISTRIBUTION CONTOUR DIAGRAM (Louvered Ceiling lights on: 2,4 & 8)



1.SYMMETRICAL TABLE LUMINAIRE



2.ASYMMETRICAL TABLE LUMINAIRE

CONTOUR DIAGRAM FOR THE TABLE LUMINAIRES (SYMETRICAL/ASSYMETRICAL)
Distance from bulb to table = 12" (LUX)

Appendix H

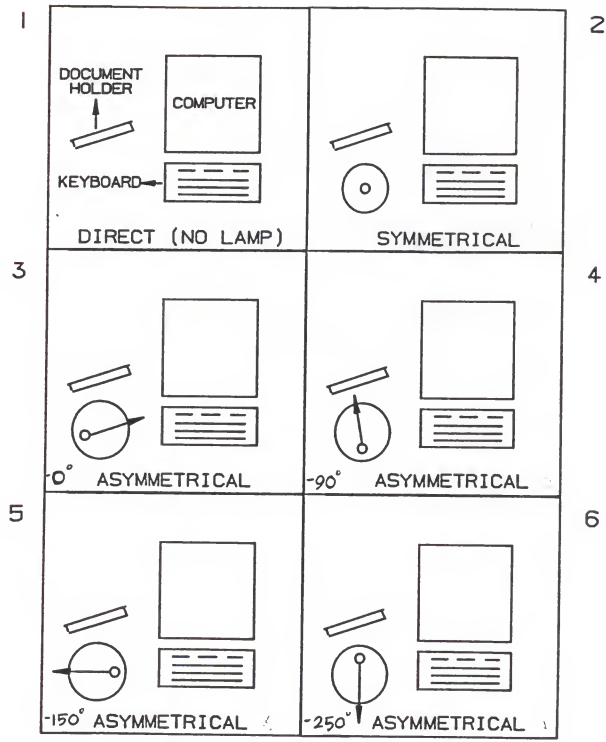
RANDOM ASSIGNMENT OF CONDITIONS

To insure that the assignment of the lighting condition to subjects were truly randomized, the following procedure was used to design this experiment. A hand held calculator random generator was used for this procedure.

CONDITIONS

SUBJECTS	1	2	3	4	5	6
1	3	1	5	6	4	2
2	6	3	2	5	4	1
3	2	1	5	4	6	3
4	1	2	3	5	6	4
5	2	4	3	6	1	5
6	4	6	1	3	5	2
7	5	4	3	1	6	2
8	4	3	2	5	1	6
9	1	6	3	4	2	5
10	3	2	4	5	6	1
11	6	2	1	3	4	5
12	2	6	5	3	4	1
13	1	2	5	6	3	4
14	2	3	6	4	5	1
15	1	3	5	4	6	2
16	5	4	6	1	3	2
17	2	5	1	6	4	3
18	1	3	4	2	6	5
19	1	6	2	4	3	5
20	2	4	5	1	3	6

APPENDIX I

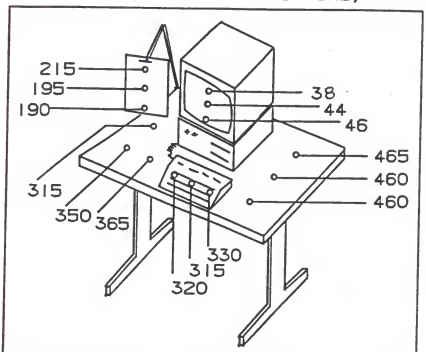


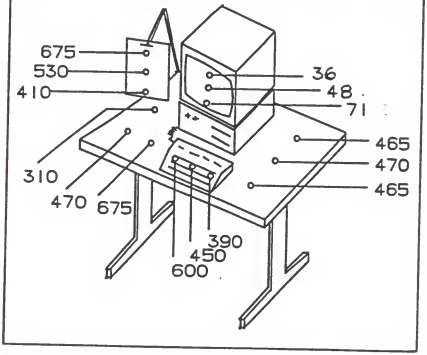
The six different table luminaire positions (conditions)

APPENDIX I.a

Illumination levels at workstation (lux) for the six conditions

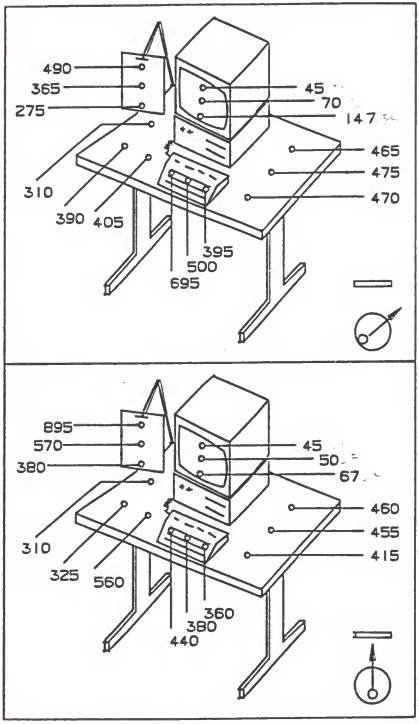
1. DIRECT (NO TABLE LUMINAIRE)





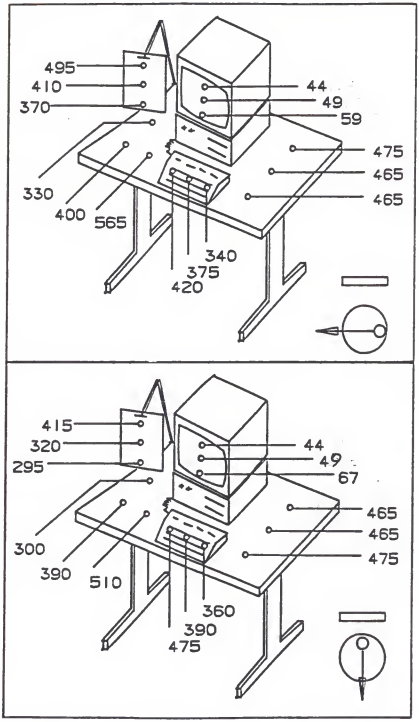
2. SYMMETRICAL TABLE LUMINAIRE

3. ASYMMETRICAL TABLE LUMINAIRE(POS 1)



4. ASYMMETRICAL TABLE LUMINAIRE(POS 2)

5. ASYMMETRICAL TABLE LUMINAIRE (POS 3)



6. ASYMMETRICAL TABLE LUMINAIRE (POS 4)

Appendix J

STATISTICAL ANALYSIS

J.1 DATA EXAMINATION

The data was sorted by condition and checked for typographical errors. Then it was resorted by subject and checked. All data entry errors were corrected. The data was tested for outliers. Prior to further examination, the data was converted from votes 1 to 7 to a score in percent by using the formula shown below:

Score (in percent) = ((vote - 1) / 6) * (100)

J.2 FACTOR ANALYSIS

A factor analysis was made on the votes from the 12 adjectives (Appendix C) that describes the workstation and the general illumination environments. The purpose of this analysis was to determine if the votes for these adjectives could be collected into groups. This collection not only reduced the number of variables but the new variables were a better description of the subject's preference for the conditioned being examined.

The analysis of results determined that the workstation illumination votes could be collected into one variable and the general illumination votes could be collected into

another. The variable for the 6 adjectives describing the workstation was given the variable name "workstation" and the variable for the general environment was named "room illumination". Tables J.1 and J.2 are the squared multiple correlations and the standardized scoring coefficients for the variables workstation and room illumination respectively.

Table J.1 Factor Analysis for Workstation

ADJECTIVE	SCORING COEFFICIENT
agreeable	0.10355
desirable	0.21464
good	0.16215
satisfied with	0.23051
acceptable	0.18563
content with	0.15576

Squared Multiple Correlations with each factor: 0.972

Table J.2 Factor Analysis for General Environment

ADJECTIVE	SCORING COEFFICIENT
pleasant	0.21543
harmony	0.34425
relaxed	0.14344
interesting	0.07308
like	0.25753
sociable	0.08730

Squared Multiple Correlations with each factor: 0.925

J.3 WORKSTATION LIGHTING

An analysis of variance procedure was run on a randomized complete block design model. LSD tests of differences, using significance level of 0.05, were run.

Table J.3 Analysis of Variance Procedure for Workstation

SOURCE	DF	SS	F VALUE	PR>F
CNO	5	4042	2.08	0.0785
SNO	14	15722	2.89	0.0018
Error	70	27237		

legend:

CNO: Condition Number

SNO: Subject Number

Table J.4: LSD Test for "Workstation"

Least Significant Difference is 15.7

LSD	T Test	Mean	Condition No.
A	A	74.2	5
A	A	71.7	3
A	A	68.1	6
A B	A B	66.0	1
A B	A B	61.1	2
B	B	51.7	4

Means with the same letter are not significantly different.

J.4 GENERAL LIGHTING

An analysis of variance procedure was run on the model. LSD tests of differences, using significance level of 0.05, were run.

Table J.5 ANOVA Procedure for "Room Illumination"

SOURCE	DF	SS	F VALUE	PR>F
CNO	5	1678	1.97	0.0940
SNO	14	26569	11.13	0.0001
Error	70	11932		

legend:

CNO: Condition Number

SNO: Subject Number

Table J.6: LSD Test for "Room Illumination"

Least Significant Difference is 9.5

LSD	T Test	Mean	Condition No.
A	A	77.0	5
A B	A B	71.0	6
A B	A B	68.6	3
A B	B	68.2	1
B	B	64.6	4
B	B	64.4	2

Means with the same letter are not significantly different.

J.5 PERFORMANCE

The criteria number of words per minute and percent of errors (number of errors / Number of words typed) were examined.

J.5.1 Number of Words typed:

The Analysis of Variance Procedure and the results for the LSD test were as follows:

Table J.7 ANOVA Procedure for Words per Minute

Mean Words per Minute = 22.8

SOURCE	DF	SS	F VALUE	PR>F
CNO	5	154	12.64	0.0001
SNO	14	6776	198.37	0.0001
Error	70	171		

legend:

CNO: Condition Number

SNO: Subject Number

Table J.8: LSD Test for the criterion words per minute

Least Significant Difference is 1.1

LSD	T Test	Mean	Condition No.
A	A	24.4	6
A	A	24.2	5
B	B	22.9	2
B	B	22.9	3
C	C	21.6	1
C	C	20.8	4

Means with the same letters are not significantly different

J.5.2 **Percent of Errors**

The Analysis of Variance procedure and the results of the LSD test were as follows:

Table J.9 ANOVA Procedure for Percent Errors

Mean Error Percentage = 3.7

SOURCE	DF	SS	F VALUE	PR>F
CNO	5	0.003	1.52	0.1957
SNO	14	0.043	7.62	0.0001
Error	70	0.285		

legend:

CNO: Condition Number

SNO: Subject Number

Table J.10: LSD test for the criterion Percent Error

Least significant Difference is 0.015

LSD	T Test	Mean	Condition No.
A	A	0.044	1
A	A	0.043	3
A B	A	0.038	2
A B	A	0.037	4
A B	A	0.036	5
B	A	0.026	6

Means with the same letter are not significantly different

J.6 TESTS ON ADJECTIVES

An analysis of variance procedure was carried out on the model for each of the 12 adjectives used in the lighting environmental ballot (Appendix C). Multiple comparisons were made using the Least Significant Difference test. Table J.11 to Table J.22 illustrates the results.

Table J.11: LSD for adjective "agreeable"

Least Significant Difference is 1.0

Groupings		Mean	Condition No.
A		5.4	5
A	B	5.1	1
A	B	5.1	3
	B	5.1	6
C	B	4.3	2
C		4.1	4

Means with the same letters are not significantly different.

Table J.12: LSD for adjective "desirable"

Least Significant Difference is 1.0

Groupings		Mean	Condition No.
A		5.0	5
A	B	4.8	3
A	B	4.7	6
A	B	4.5	1
A	B	4.4	2
	B	3.8	4

Means with the same letters are not significantly different.

Table J.13: LSD for adjective "good"

Least Significant Difference is 1.0

Groupings		Mean	Condition No.
A		5.1	5
A	B	4.9	3
A	B	4.9	6
A	B	4.3	1
A	B	4.3	2
	B	4.0	4

Means with the same letters are not significantly different.

Table J.14: LSD for adjective "satisfied with"

Least Significant Difference is 0.9

Groupings		Mean	Condition No.
A		5.3	5
A		5.2	3
A		5.0	6
A		4.9	1
A	B	4.5	2
	B	3.9	4

Means with the same letters are not significantly different.

Table J.15: LSD for adjective "acceptable"

Least Significant Difference is 0.9

Groupings	Mean	Condition No.
A	5.4	3
A	5.3	5
A	5.1	1
A B	4.9	6
A B	4.8	2
B	4.1	4

Means with the same letters are not significantly different.

Table J.16: LSD for adjective "content with"

Least Significant Difference is 0.9

Groupings	Mean	Condition No.
A	5.2	5
A	5.1	3
A	4.9	1
A	4.8	6
A B	4.5	2
B	3.9	4

Means with the same letters are not significantly different.

Table J.17: LSD for adjective "pleasant"

Least Significant Difference is 0.7

Groupings		Mean	Condition No.
A		5.4	5
A	B	5.0	1
A	B	5.0	6
A	B	4.9	3
	B	4.6	4
	B	4.5	2

Means with the same letters are not significantly different.

Table J.18: LSD for adjective "harmony"

Least Significant Difference is 0.6

Groupings		Mean	Condition No.
A		5.3	5
A	B	4.7	1
A	B	4.7	6
	B	4.4	3
	B	4.3	4
	B	4.3	2

Means with the same letters are not significantly different.

Table J.19: LSD for adjective "relaxed"

Least Significant Difference is 0.7

Groupings	Mean	Condition No.
A	5.3	5
A	5.3	1
A	5.1	6
A	5.0	4
A	4.9	3
A	4.9	2

Means with the same letters are not significantly different.

Table J.20: LSD for adjective "interesting"

Least Significant Difference is 0.6

Groupings	Mean	Condition No.
A	4.5	5
A	4.5	3
A B	4.3	2
A B	4.2	4
A B	4.1	6
B	3.8	1

Means with the same letters are not significantly different.

Table J.21: LSD for adjective "like"

Least Significant Difference is 0.7

Groupings	Mean	Condition No.
A	4.9	5
A B	4.8	3
A B	4.7	6
A B	4.4	2
A B	4.3	4
B	4.2	1

Means with the same letters are not significantly different.

Table J.22: LSD for adjective "sociable"

Least Significant Difference is 0.7

Groupings	Mean	Condition No.
A	4.8	6
A	4.7	5
A	4.6	3
A	4.5	1
A	4.5	2
A	4.4	4

Means with the same letters are not significantly different.

APPENDIX K

Experiment Data

Legend:
S : subject
A : age
C : condition
NW: no. of words/6 min
NE: no. of errors/6 min

Votes (1-7 scale)
a: agreeable
b: desirable
c: good
d: satisfied
e: acceptable
f: content
g: pleasant
h: harmony
i: relaxed
j: interesting
k: like
l: sociable

S	A	C	NW	NE	a	b	c	d	e	f	g	h	i	j	k	l
1	21	3	148	9	3	2	3	3	3	2	6	4	6	1	6	4
1	21	1	149	3	6	5	5	5	5	6	6	6	6	2	5	4
1	21	5	157	6	6	5	5	6	6	6	6	6	6	2	5	5
1	21	6	153	5	4	4	4	4	4	4	4	4	5	2	5	5
1	21	4	135	3	3	3	3	3	4	4	5	3	4	3	5	5
1	21	2	151	2	6	5	5	6	6	6	6	5	5	3	4	5
2	22	2	159	4	6	7	6	7	7	6	6	6	5	5	6	4
2	22	1	160	0	5	5	4	4	5	4	6	6	6	5	6	4
2	22	3	139	3	5	6	6	6	6	6	5	6	6	5	5	4
2	22	5	186	1	6	6	6	6	6	6	6	6	6	5	6	5
2	22	6	173	0	5	5	5	6	6	6	6	5	5	4	5	4
2	22	4	147	1	6	6	6	7	7	6	6	6	6	5	6	5
3	24	3	90	3	3	3	3	4	3	3	3	2	2	4	2	4
3	24	2	95	2	1	1	1	1	2	2	4	3	2	6	4	6
3	24	1	74	1	6	6	6	6	6	5	3	2	2	3	2	2
3	24	5	102	2	5	3	4	3	2	2	4	3	2	4	3	3
3	24	4	77	2	2	2	2	1	2	1	4	3	2	4	2	3
3	24	6	81	1	2	1	2	2	1	1	3	2	2	2	2	4
4	22	1	168	6	5	5	5	6	6	5	5	5	6	5	5	5
4	22	2	186	5	6	6	6	6	6	6	5	5	6	5	6	5
4	22	3	193	2	7	6	6	7	7	7	6	6	6	5	6	5
4	22	4	166	3	5	4	5	5	5	4	5	5	6	5	5	4
4	22	6	213	3	5	5	5	5	4	4	5	5	6	4	4	4
4	22	5	223	3	6	6	6	6	6	6	5	5	6	4	5	4
5	21	5	269	11	7	7	7	7	7	7	7	7	6	6	6	6
5	21	2	233	11	3	2	2	3	4	3	4	6	7	5	4	4
5	21	4	239	5	4	4	3	4	4	4	5	5	5	4	4	4
5	21	3	260	9	6	6	6	6	7	6	6	5	5	6	6	5
5	21	6	261	16	7	7	6	6	7	6	6	7	5	6	6	6

S	A	C	NW	NE	a	b	c	d	e	f	g	h	i	j	k	l
5	21	1	227	4	4	4	3	3	4	4	4	5	6	6	4	6
6	22	4	149	8	5	2	4	3	2	4	6	6	7	6	6	7
6	22	6	168	6	5	6	6	6	6	6	7	6	7	5	6	6
6	22	1	142	7	6	7	6	7	6	6	6	6	6	5	5	6
6	22	3	149	1	6	5	6	6	6	5	6	6	7	5	7	6
6	22	5	158	2	7	7	7	7	7	7	6	6	6	5	6	5
6	22	2	156	1	6	5	5	5	6	6	6	6	7	5	5	7
7	22	5	199	3	4	2	2	3	3	3	4	5	6	5	5	6
7	22	4	189	6	2	2	1	2	2	2	5	5	6	3	5	4
7	22	3	220	4	6	5	5	6	6	5	5	5	6	4	5	5
7	22	1	206	7	6	5	6	5	5	5	6	6	6	4	5	5
7	22	6	235	12	6	6	6	6	6	6	6	6	6	4	5	5
7	22	2	217	9	6	6	6	5	6	5	5	5	6	4	5	5
8	22	6	126	5	6	5	6	5	5	6	5	5	5	6	6	6
8	22	4	93	2	3	3	4	4	2	2	5	4	6	4	3	2
8	22	3	109	2	5	5	4	4	5	4	4	5	4	4	4	5
8	22	2	111	3	3	3	2	2	2	4	3	4	4	3	3	3
8	22	5	121	4	5	5	5	5	5	4	6	5	4	5	5	5
8	22	1	114	2	6	5	5	6	6	6	5	4	4	4	4	3
9	22	5	179	1	6	5	5	6	5	5	5	4	5	4	4	3
9	22	6	185	1	4	3	3	4	3	3	3	3	4	3	3	2
9	22	1	157	1	3	2	1	3	4	4	4	2	3	2	2	1
9	22	2	181	1	5	4	3	4	3	3	4	3	4	3	4	3
9	22	3	172	8	4	4	3	4	4	4	3	5	4	4	3	3
9	22	4	153	4	5	5	4	4	5	4	3	2	4	3	3	3
10	21	1	113	1	6	2	3	4	4	4	3	2	6	4	4	5
10	21	2	137	5	5	5	6	6	6	6	4	3	6	4	3	5
10	21	3	118	6	7	6	6	6	6	6	4	3	6	4	3	5
10	21	4	115	2	5	6	6	5	6	6	4	3	6	4	3	6
10	21	5	119	3	5	5	6	6	6	6	4	4	6	4	3	5
10	21	6	136	1	6	6	6	6	5	5	5	3	6	4	4	4
11	21	5	119	12	6	6	6	6	7	6	6	7	6	5	6	6
11	21	6	105	2	7	6	7	7	7	7	6	6	6	5	6	5
11	21	2	108	9	2	3	3	3	4	4	3	3	2	3	3	3
11	21	1	112	10	6	6	6	6	6	6	6	6	7	5	6	6
11	21	3	121	9	3	3	4	4	5	4	3	3	3	5	4	5
11	21	4	111	11	6	6	7	7	7	7	6	6	7	6	7	6
14	26	1	77	7	6	5	5	5	5	6	6	5	6	4	5	5
14	26	2	69	7	2	4	6	6	5	3	3	2	5	4	5	3
14	26	3	70	6	4	5	5	5	5	5	5	5	4	6	6	6
14	26	6	80	5	6	5	6	4	5	6	5	5	6	5	6	6
14	26	4	64	5	3	4	4	3	3	3	2	3	2	3	2	3
14	26	5	76	8	4	5	4	5	5	4	5	4	5	4	4	4
15	25	2	100	1	3	4	2	3	3	4	5	5	4	5	4	4
15	25	1	100	7	4	4	3	5	5	3	6	5	6	2	4	6
15	25	3	111	7	6	5	6	6	6	6	5	5	4	4	3	4
15	25	5	111	3	6	5	6	4	5	6	7	6	6	5	6	4

S	A	C	NW	NE	a	b	c	d	e	f	g	h	i	j	k	l
15	25	4	104	5	2	2	2	1	2	2	4	3	2	2	2	4
15	25	6	114	1	3	2	2	3	4	3	5	5	4	4	5	4
18	21	5	112	2	3	3	3	4	4	5	6	6	6	6	6	6
18	21	1	92	12	4	3	3	4	5	4	5	6	6	3	4	6
18	21	3	103	7	6	6	6	6	6	7	7	5	6	6	6	5
18	21	4	85	5	6	5	6	5	6	5	6	7	7	7	6	6
18	21	2	109	8	7	7	7	7	7	7	7	6	6	6	6	6
18	21	6	114	3	6	6	6	6	6	5	6	5	7	6	6	6
19	25	1	50	4	3	3	3	4	5	5	5	4	3	3	2	4
19	25	6	52	1	4	3	3	5	5	4	3	4	3	2	2	5
19	25	2	52	3	3	4	3	4	5	4	3	3	4	3	4	5
19	25	4	43	1	4	3	3	4	5	4	3	4	5	4	5	4
19	25	3	54	3	5	5	5	5	6	6	4	3	4	4	5	3
19	25	5	51	4	5	5	4	6	6	6	4	5	4	3	4	3

ASYMMETRICAL TASK LIGHTING
FOR
WORKSTATIONS WITH
VISUAL DISPLAYS UNITS

by

SANTHANAKRISHNAN N.

B.Tech (Mechanical), University of Kerala, India, 1986

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

College of Engineering

Department of Industrial Engineering

Kansas State University

Manhattan, Kansas

1988

ASYMMETRICAL TASK LIGHTING FOR WORKSTATIONS WITH VISUAL DISPLAY UNITS

The number of VDUs in all aspects of office automation are continuing to increase at a rapid rate. Estimates are that by 1990 the number of terminals will increase to 1 for 3 office workers.

Lighting for VDUs at a workstation presents a challenge as a typical task has different lighting requirements for the screen, source document and the keyboard. Task lighting is an approach to solve this dilemma. This experiment investigated the preference of 6 different task light conditions by the subjects. The workstation illumination was constant for all the conditions. Task lighting was provided by an asymmetrical and a symmetrical table luminaires. VDU operators preferred the asymmetrical table luminaire as light can be directed away from the screen. They preferred task document illumination between 300 to 500 lux. When the level was above this level it was less preferred. The performance of the VDU operators was found to better in conditions were the asymmetrical luminaire directed away from the screen. The words typed per minute for a asymmetrical luminaire directed away from a VDU was 24.4, 22.9 for symmetrical table luminaire and 21.6 for without table luminaire and the error percentage for the above conditions were 2.6%, 3.8% and 4.4% respectively.